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(54) TRANSCALENT ASSEMBLY

(71) We, RCA CORPORATION, a corporation organized under the laws of the State of Delaware, United State of America, of 30 Rockefeller Plaza, City and State of New York, 10020, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to means for cooling devices and particularly to a transcalent assembly.

The term "transcalent assembly" as used in the present specification and in the appended claims is to be understood as denoting an arrangement in which capillary means are employed to supply cooling fluid to a surface from which heat is to be removed by evaporation of the fluid.

In the prior art, to provide heat dissipation from an electrical device, such as a silicon rectifier or a transistor, for example, the device is mounted on a heat sink body. The heat sink body is generally of relatively large mass to provide a heat-acceptance capability and may be, for example, a solid block of heat conducting material, such as copper. Such mounting of the device may be done by bonding, as by soldering, for example, a relatively large proportion of a device face directly to the heat sink body. Such means of heat dissipation from an electrical device is of limited commercial desirability, however, for several reasons. First, where a large proportion of the device face is bonded directly to the heat sink body, heating of such a device, whether the heating results from the bonding process or from the operation of the device, introduces strains in the device. These strains are attributable to the different coefficients of thermal expansion of the device and of the heat sink body. While the straining of the device may be somewhat alleviated by reducing the proportion of the device face that is bonded to the heat sink body, this brings about a decrease in the heat transfer from the device to the heat sink body. Furthermore, where "soft" solders are used to bond large areas of the device to the heat sink body, there arises the problem of thermal fatigue of the solder when the device is subjected to a number of temperature cycles. On the other hand, where a "hard" solder is used for bonding the device, it is often necessary to employ a strain isolation disc of, for example, tungsten or molybdenum, between the device and the heat sink body to protect the device. In addition, both the device-solder and the solder-heat sink body interfaces cause a relatively high level of thermal impedance, making heat dissipation from the device more difficult. Also, the relatively large mass of a heat sink body causes the device-heat sink assembly to be of relatively great weight, thereby limiting its usefulness.

Cooling of lasers in the prior art may be achieved by a different method. In the case of a gaseous or liquid laser, for example, having an outer envelope, the heat generated by the laser is transferred to the laser envelope, from which it is dissipated. Where a laser is operated at relatively low power levels, forced air cooling of the laser envelope during operation generally provides sufficient heat dissipation from the laser. Where the laser is operated at higher power levels, however, there is a poor heat transfer coefficient from the laser envelope to a gas, such as air, flowing over the envelope so that the quantity of heat removed from the laser is limited. As a result, liquid cooling instead of air cooling, is generally employed. Such liquid cooling requires, however, either a large

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reservoir of coolant or a closed re-cycling coolant system. In the case of the coolant reservoir, coolant is continuously drawn from the reservoir and passed over the laser surface, after which the coolant is discarded. In the closed system, heat is first removed from the laser envelope by a pumped, continuously re-circulating flow of liquid over the laser envelope surface, followed by transfer of the heat from the liquid to the ambience by means of a large area heat exchanger attached to the closed system. Both such means of cooling lasers are of limited commercial value, however, because of their relatively large volume and weight. These cooling means may also be used for solid state lasers, but there, too, such means are of limited commercial value for the above reasons.

According to the present invention there is provided a trancalent assembly comprising a hermetically sealed, self-contained vessel including an envelope portion having a discontinuity in the wall thereof, and a device from which heat is to be removed disposed in relation to said envelope portion such that a portion of the external surface of said device completely closes said discontinuity and constitutes a portion of the interior surface of said vessel, a capillary structure disposed at the interior surface of said vessel, and overlying at least a portion of said external surface of said device, and a vaporizable working medium disposed within said vessel, at least a portion of said working medium being retained by said capillary structure in direct contact with said external surface of said device.

Both electrical and non-electrical devices can be cooled by this invention. Among the electrical devices that may be cooled by this invention are various types of lasers and semiconductor pellets or chips for diode junction lasers, silican rectifiers, transistors, etc.

According to an embodiment of the invention, a device having more than one external surface may have a transcalent assembly as described above integral with each external surface. By providing a transcalent assembly having as an integral part thereof, an external surfaces of a device which is to be cooled, one or more disadvantages of the prior art devices are overcome. Some of the disadvantages of the novel device assembly are: improved heat transfer from a device by virtue of both a minimal thermal impedance and enhanced heat transfer coefficient between the device and the working medium; the reduction of the size and weight of the cooling means for a device; and a reduced possibility of strains in the device.

FIGURE 1 is a sectional perspective view of one embodiment of a transcalent assembly including an electrical device containing a p-n junction;

FIGURE 2 is a partial sectional elevation view of another embodiment of the invention where the device contains a p-n junction;

FIGURE 3 is a sectional perspective view of another embodiment of the invention;

FIGURE 4 is a fragmentary sectional end view of another embodiment of the invention including a laser, and;

FIGURE 5 is a fragmentary sectional view taken along the longitudinal axis 5—5 of the embodiment shown in FIGURE 4.

Referring to FIGURE 1, there is shown a transcalent assembly 10 which includes a hermetically sealed, self-contained vessel 12 of integral structure. The vessel 12 is comprised of an envelope portion 14 having an electrical device 16 bonded thereto. As used herein, the term "envelope portion" is defined as a hollow body which does not completely enclose the space contained therein for reason of an opening or other discontinuity in the wall thereof. While the discontinuity of the envelope portion 14 is illustrated as an open end thereof, other forms of discontinuities may be used. The envelope portion 14 is made of a heat conducting material, such as copper, for example. The electrical device 16, which has an external surface 18, is disposed on the envelope portion 14 such that the discontinuity thereof is completely closed by the device 16. At least a portion of the external surface 18 constitutes an integral portion of the interior surface 22 of the vessel 12. The external surface 18 of the device 16 constituting a portion of the interior surface 22 should be a surface that is heated by the operation of the device and is preferably that surface of the device which exhibits the greatest amount of heating. The size of the discontinuity is preferred to be only slightly smaller than the dimensions of the external surface 18 so that only a relatively small proportion of the external surface 18 is covered by and bonded to, the envelope portion 14. The device 16 is bonded to the envelope portion 14 by techniques known in the art, such as by soldering with a gold-silicon eutectic composition. If the device has an outside diameter of about 950 mils for example, the bonded portion extends only 25 mils from the edge so that an essentially circular area of about 900 mils diameter is in contact with the working medium. By limiting the bonded area of the device 16 to a relatively small proportion of the external surface 18 thereof, the aforementioned strains in the devices in the prior art are significantly reduced. This reduction in the size of the bonded area does not, however, result in any significant reduction in heat transfer from the device, this by virtue of the invention described herein.

The electrical device 16 may be, for example, a semiconductor chip or pellet, containing a single p-n junction (e.g., a silicon

rectifier or a diode junction laser), as shown in FIGURE 1. Alternatively, the invention may be used to cool other electrical devices, such as semi-conductor chips, or pellets, containing more than a single p-n junction (e.g., silicon-controlled rectifiers or transistors) and non-semiconductor devices (e.g., gas lasers, liquid lasers, and crystal lasers). It is preferred that the semiconductor devices be mounted on the vessel 12 such that the p-n junctions thereof are not exposed to the working medium within the vessel, but instead, terminate, as shown in FIGURE 1, in regions removed from the discontinuity of the vessel. The p-n junctions of the device are thereby protected from any possible damaging effects of the working medium. Semiconductor devices 19 (FIGURE 2) having p-n junctions not extending to the periphery thereof may be mounted on a vessel 14 as shown in FIGURE 2. While FIGURE 1 shows the envelope portion 14 to be cyclindrical, other shapes, such as cubes, may be used.

A capillary structure 20 having channels of capillary dimension therein is disposed overlying the interior surface 22 of the vessel 12. As used herein with respect to the disposition of the capillary structure 20, the term "overlying" is to be understood as applying to cases in which the capillary structure is disposed either in contact with or in close proximity to the interior surface 22 of the vessel. Where the capillary structure 20 is disposed in close proximity to the interior surface 22, the separation between the capillary structure 20 and the interior surface 22 is, for reasons given below, not greater than capillary dimension. It is necessary that at least a portion of the capillary structure 20 be disposed at and shall overlie at least a portion of the external surface 18 of the electrical device 16 in order to insure adequate cooling of the device 16, as explained below. If placed in contact with surface 18 the capillary structure 20 aids in distributing over the exterior surface 18 any electrical potential applied to the device 16. The capillary structure 20 is shown as a hollow cylinder having a single open end but capillary structures of other shapes may be used. The capillary structure 20 is made, for example, by pressing and sintering a suitable metal powder, such as copper, according to techniques known in the metallurgical art. Within the vessel 12 there is disposed a quantity of working medium (not shown) which is vaporizable at the operating temperature range of the particular electrical device 16 and is chemically compatible with the vessel 12. For capillary pumping of the cooling medium, it is necessary that such working medium shall be either in a liquid state or liquefiable within the operating temperature range of the particular electrical device 16 and that the liquid working medium shall "wet" the capillary structure. Such a working medium may be water, acetone, or a dielectric material, such as freon. It is generally desirable that the quantity of working medium in the vessel 12 shall be at least sufficient to completely fill the capillaries of the structure 20. It is necessary that at least a portion of the working medium be retained, by capillary action, in that portion of the capillary structure 20 disposed at the external surface 18 of the electrical device 16 in direct physical contact with the external surface 18. By providing for the direct physical contact of the working medium with the external surface 18 of the device 16 with no physical structure intervening therebetween, there results a minimum impedance to the flow of heat from the device 16 to the working medium and a consequent higher level of heat dissipation from the device 16. Also, there is a relatively high heat transfer coefficient between the device 16 and the liquid working medium, providing further improvement in heat dissipation from the device 16. Where the capillary structure 20 is separated from the interior surface 22 of the vessel 12, the restriction of the dimension of this separation to less than capillary size insures that working medium will be retained, by capillary action, in direct contact with the device 16.

Sealing means 30 are provided to protect exposed portions of the electrical device 16 and, particularly, the p-n junction, from ambient conditions. The sealing means 30 are comprised of a first metal portion 32, bonded, by brazing, for example, to the outer surface of the envelope 14; an insulating means 34, made of ceramic, for example, and bonded to the first metal portion by a first ceramic-to-metal seal; and a second metal portion 36 bonded to the insulating means 34 by a second ceramic-to-metal seal. The sealing means 30 defines a hermetically sealed, isolated region 38 around the device 16, which region 38 may be filled with a dry, inert gas to further protect the device 16 from ambient conditions.

Potential may be applied to the device 16 from a potential source (not shown) by external electrical leads 40 and 42 attached to the first and second metal portions 32 and 36, respectively. The first metal portion 32 is electrically connected to one portion of the device 16 via the conducting envelope portion 14. The second metal portion 36 is electrically connected to another portion of the device 16 via internal connecting means 44 and is electrically isolated from the first metal portion 32 by insulating means 34. Hence, by arranging the various regions of an electrical device 16, such as a silicon rectifier chip, for example, such that one such region (e.g., the p-type conductivity region of the device 16) thereof is in contact with the envelope portion 14 and another such region (e.g., the n-type conductivity region of the device 16) is in

contact with internal connecting means 44, electrical energy can be provided to the device via external connecting means 40 and 42. The particular means for providing electrical energy may be adapted to the electrical device that is used, more than two external leads being provided where necessary. Where more than two external leads are necessary, the sealing means 30 may be provided with additional metal portions which are electrically isolated by additional insulating means in the manner described above. Cooling fins 46 are mounted on the outer surface 23 of the envelope portion 14 at regions remote from the device 16.

In the operation of the transcalent assembly 10, the electrical device 16 is operated in standard fashion with potential being applied via external electrical leads 40 and 42. The heat generated by the electrical device 16 is transferred to the working medium, which is in direct contact therewith. When sufficient quantities of heat are generated by the device 16, the working medium proximate to the external surface 18 of the device 16 is vaporized. Such vaporization continues as long as sufficient heat is generated by the device 16. The working material vapor is driven through the interior 43 of the envelope portion 14 toward the cooler end of the envelope portion 14 which is remote from the device 16. At this remote end, the vapor surrenders its latent heat of vaporization to the capillary structure 20 and to any exposed portions of the walls of the envelope portion 14 and condenses thereon. The working medium vapor is so driven by the vapor pressure gradient within the vessel 12, the vapor pressure being higher in the vicinity of the electrical device 16 and lower at the remote end. This pressure gradient is brought about by the evaporation of liquid working medium in the vicinity of the device 16 and the condensation of working medium vapor in the cooler regions of the vessel 12 removed from the device 16. By disposing the capillary structure 20 on or in close proximity with the interior surface 22 of the vessel 12, heat surrendered to the capillary structure 20 is transferred to the walls of the envelope portion 14. Where the capillary structure 20 is disposed in close proximity to the interior surface 22, working medium retained therebetween by capillary action serves in the transfer of heat from the capillary structure 20 to the walls of the envelope portion 14. The heat surrendered to the capillary structure 20 and the walls of the envelope portion 14 is dissipated to the ambience by the cooling fins 46. The condensed working medium is absorbed by the capillary structure 20, which then conducts the condensed working medium toward the device 16 by capillary action. Because of the portion of the capillary structure 20 disposed thereat, the device 16 is constantly provided with working medium in the liquid state. As a result, heat is continuously transferred away from the device 16 by the evaporation of the working medium.

The direct contact of the working medium of the transcalent assembly 10 with the electrical device 16 allows the transfer of heat from the device 16 to the working medium with very little thermal impedance, thereby improving the cooling of the device 16. Also, improved cooling of the device 16 results by virtue of the evaporation of working medium by the device 16. This is because of the extraction, from the device 16, of large quantities of heat in the form of latent heat of vaporization and in the form of specific heat to raise the temperature of the working medium to the evaporation point. Furthermore, since the capillary structure 20 provides working medium to the device 16 by capillary action, the provision of working medium to the device 16 is substantially independent of gravity forces. As a result, the transcalent assembly 10 is operable in any position or angle.

In another embodiment of the invention illustrated in FIGURE 3, the combination 50 of a device to be cooled and a transcalent assembly includes a duplication of the envelope portion 14 and the capillary structure 20 shown in FIGURE 1. The combination 50 includes a single electrical device 52 which has two opposed external surfaces 54 and 56. An open-ended envelope portion 58 and 60 is applied to each external surface 54 and 56, respectively, of the device 52. Each envelope portion 58 and 60 is so disposed that an external surface of the device 52 hermetically closes the respective open ends, or discontinuities, thereof, thereby producing two non-communicating, self-contained vessels 62 and 64. A respective capillary structure 66 and 68 is disposed at the inner walls of each of the respective vessels 62 and 64, at least a portion of each capillary structure being disposed at each device external surface 54 and 56 of the device 52 to be cooled. Within each vessel there is disposed a vaporizable working material, at least a portion of which working material is retained by the capillary structure 66 and 68 and at least some portion of which working medium is in direct physical contact with the device 52 at the external surfaces 54 and 56 thereof. Cooling fine 70 and sealing means 72 are provided, as in the embodiment shown in FIGURE 1. Effectively, the assembly 50 in FIGURE 3 is a double structure of the assembly 10 in FIGURE 1 and incorporates the same types of materials. By providing a second vessel 64, the heat transfer capability of the transcalent assembly 50 is further increased, leading to further improvement in the operation of the electrical device 52.

In another embodiment (FIGURES 4 and 5) of this invention, the combination 100 of

a device to be cooled and a transcalent assembly includes a hermetically sealed, self-contained vessel 102 comprising both an envelope 104 and a laser 106. While a liquid, gaseous, or crystal laser may be used, in FIGURES 4 and 5 the laser 106 is illustrated, for purposes of simplicity, as the envelope 108, only, of a liquid or gaseous laser, with Brewster windows 110 also shown. The laser envelope 108 is considered herein as an integral part of the laser device. In the case of a crystal laser, such as a ruby laser, for example, the outer peripheral portions of the laser crystal would occupy the position of the laser envelope 108. The envelope portion 104 is shown as comprised by a hollow cylinder having annular ends 105. The envelope portion 104 thus has a discontinuity in its wall, which discontinuity is the opening extending between the annular ends 105 and opposite the cylindrical portion of the envelope portion 104. The laser 106 is disposed in the envelope 104 such that the discontinuity of the envelope 104 is completely closed. The laser 106 this forms an integral part of the vessel wall, a relatively large proportion of the external surface 116 of the laser 106 comprising an integral portion of the interior surface 114 of the vessel 102. The laser device external surface which comprises a portion of the interior surface 114 should be a surface that is heated by the operation of the device and is preferably that exterior surface exhibiting the greatest amount of heating. The laser envelope 108 is hermetically sealed to the annular ends 105 of the envelope 104. Where the laser envelope 108 is made of sapphire, such sealing may be done, for example, by metallizing portions of the laser envelope 108 and brazing these metallized portions to the annular ends 105. A capillary structure 112 is disposed at the interior surface 114 of the vessel 102, at least a portion of the capillary structure 112 being disposed at the external surface 116 of the laser 106. The capillary structure 112 contains capillary channels and is produced by the techniques mentioned with regard to FIGURE 1. Electrical connection (not shown) is made to the laser through the openings in the annular ends 105 of the envelope portion 104. Cooling fins 120 are provided at the outer surface 112 of the vessel 102. Within the vessel 102, there is disposed a vaporizable working material (not shown), examples of which are given above. At least a portion of the working material is retained by the capillary structure 112 in direct physical contact with the laser envelope 108. The operation of the device assembly 100 is as described above, with working material being vaporized by heat from the laser 106 and the vapor being driven to cooler regions of the vessel 102, where the vapor surrenders heat and condenses. The direct contact of a liquid working medium with the laser 106 provides an improved heat transfer coefficient therebetween as well as a minimum impedance to the flow of heat from the laser 106 to the working medium.

While the invention has been described with respect to electrical devices, it can also be used with non-electrical devices, or apparatus, such as internal combustion engines, nuclear reactors, and molding machines, for example. Where the transcalent assembly incorporates non-electrical devices, an external surface of such a non-electrical device comprises an integral part of the interior surface of the vessel of the transcalent assembly, in the manner described above. The external surface should be one that is heated by the operation of the device and is preferably that surface exhibiting the greatest amount of heating.

It may be seen that the advantages of the invention herein include improved heat transfer from electrical and non-electrical devices, with the consequent improved operating characteristics of these devices, a significant reduction in size and weight of cooling means for an electrical device; and a significant reduction in the physical strains caused in an electrical device by thermal cycling.

WHAT WE CLAIM IS:—

1. A transcalent assembly comprising an hermetically sealed, self-contained vessel including an envelope portion having a discontinuity in the wall thereof, and a device from which heat is to be removed said device being disposed in relation to said envelope portion such that a portion of the external surface of said device completely closes said discontinuity and at least a portion of said external surface constitutes a portion of the interior surface of said vessel; a capillary structure disposed at the interior surface of said vessel and overlying at least a portion of said external surface of said device and a vaporizable working medium disposed within said vessel, at least a portion of said working medium being retained by said capillary structure and at least a portion of said working medium being in direct contact with said external surface of said device.

2. A transcalent assembly in accordance with claim 1 wherein said device is an electrical device.

3. A transcalent assembly in accordance with claim 2 wherein said electrical device contains at least one p-n junction, said electrical device being disposed such that said junction is removed from said discontinuity and is not in contact with said working medium.

4. A transcalent assembly in accordance with claim 3 wherein said electrical device is a silicon rectifier.

5. A transcalent assembly in accordance with claim 3 wherein said electrical device is a transistor.

6. A transcalent assembly in accordance with claim 3 wherein said electrical device is a diode junction laser.

7. A transcalent assembly in accordance with claim 3 wherein sealing means isolates exposed portions of said device from the ambience.

8. A transcalent assembly in accordance with claim 2 wherein said electrical device is a laser.

9. A transcalent assembly in accordance with claim 8 wherein said laser is a liquid laser.

10. A transcalent assembly in accordance with claim 8 wherein said laser is a gas laser.

11. A transcalent assembly in accordance with claim 8 wherein said laser is a crystal laser.

12. A transcalent assembly in accordance with claim 1 wherein said device is an internal combustion engine.

13. A transcalent assembly in accordance with claim 1 wherein said device is a nuclear reactor.

14. A transcalent assembly in accordance with claim 1 wherein said device is a molding machine.

15. A transcalent assembly in accordance with claim 1 wherein said envelope portion is comprised of a hollow cylindrical body having only one end thereof completely closed.

16. A transcalent assembly in accordance with claim 1, including a second hermetically sealed, self-contained vessel comprising a second envelope portion having a discontinuity in the wall thereof, said device having a second external surface and being disposed on said second envelope portion such that said device completely closes said discontinuity of said second envelope portion and at least a portion of said second external surface constitutes a portion of the interior surface of said second vessel; a second capillary structure disposed at the interior surface of said second vessel, said capillary structure covering at least a portion of said second external surface; and a vaporizable working medium disposed within said second vessel, at least a portion of said working medium being retained by said second capillary structure and at least a portion of said working medium being in direct contact with said second external surface of said device.

17. A transcalent assembly substantially as described with reference to the accompanying drawings.

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1295775 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

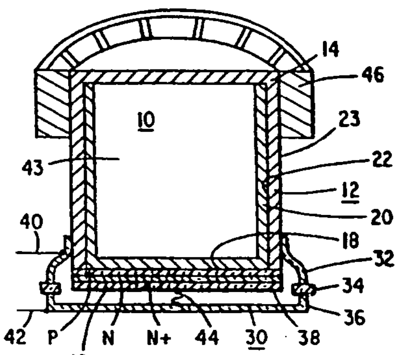

Fig. 1.

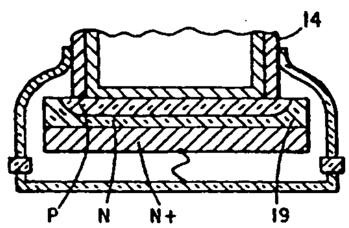

Fig. 2.

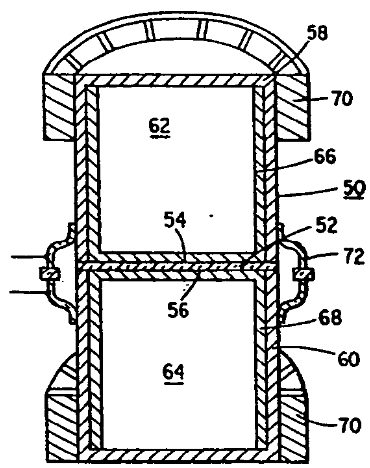

Fig. 3

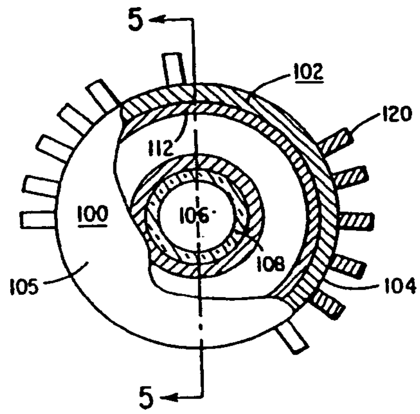
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Fig. 4.

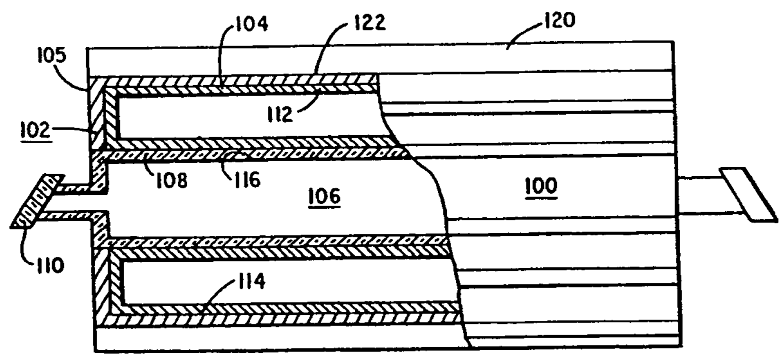
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Fig. 5.